

# The History of Driving Simulator for Road Safety Study

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## ABSTRACT

The road accidents are used to be happened by combination of three causes: driver, vehicle and road environment. To reduce the road accidents, it should be studied of the interaction between the driver and road. A driving simulator is widely known as a good tool for this kind of study.

The driving Simulator, K-ROADS has been developed for construction researchers to evaluate various road alignments, safety facilities and scenic view since 2003. The simulator is composed of several subsystems such as visual system, motion system, and automobile dynamics. (1) The motion system has 2 motion generators of 4-axis and 6-axis which reproduce the high frequency vibration simulating vehicle dynamic and low frequency vibration simulating car attitude by road slope respectively. (2) The visual system has a 360 degree cylindrical screen and 8 high performance graphic computers which mount the latest 3D graphic software.

The researcher using the driving simulator must understand that the simulator's limitation of the reproducibility of road facilities could affect the driver's human factors. On the other hand, the developers of driving simulator give a careful consideration to the reproduction of visual scenes since drivers are used to estimate the road facility from the visual scene directly. Until a driving simulator could reproduce the real driving sensation enough in accordance with the test purpose, it must be developed continually.

## 1. INTRODUCTION

The road accident is occurred by combination of three causes: driver, vehicle and road environment. To reduce the road accident, one must study the interaction between the driver and road. The driving simulator is widely known as a good tool for this kind of study. In addition, it has been applied effectively many areas including traffic safety improvement study, human factor study, intelligent transportation system research, and vehicle system development. Because it give the researcher many following advantages: investigating on dangerous situations, controlled experiment conditions (the same weather and traffic conditions), and any virtual road representation that does not yet exist.

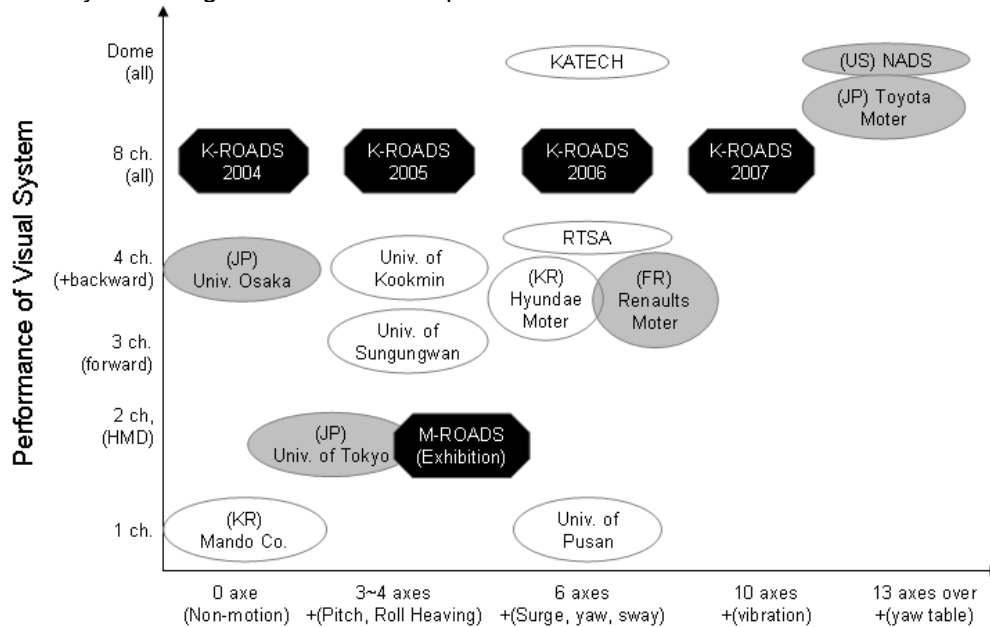
The driving simulator used the virtual reality technologies that trick similarly the human senses such as visual and motion. It is composed of several subsystems such as visual system, motion system, and automobile dynamics. Each subsystem (visual, motion, and etc) must have performance enough to reproduce the human senses. The driving simulator integrates subsystems (especially, visual and motion system) of various performances to satisfy the purpose of studies. Now, quite a few of world driving simulator have been developed for the investigation of the drivers' behavior (1) to evaluate the car parts, (2) to evaluate the road and traffic safety.

The driving simulators of many automobile companies (Hyundai, Renaults, Toyota, and etc) and universities (Kookmin, Pusan, Sungkyunkwan, Osaka, Tokyo and etc) are developed to evaluate new car parts. The other hand, NADS (National Advanced Driving Simulator, US) and RTSA-DS (Road Traffic Authority, Korea) are developed to evaluate the traffic safety.

K-ROADS (KICT – Road Analysis Driving Simulator) has been developed to the investigation of the drivers' behavior to evaluate various road alignments, safety facilities for road safety and scenic view since 2003. K-ROADS integrates several subsystems such as visual system, motion system, and automobile dynamics. (1)The motion system has 2 motion generators and reproduces both the road slope and the vibration caused by vehicle dynamic. (2) The visual system has a 360 degree cylindrical screen come within all field of vision, and the latest 3D graphic software and high performance graphic computers to reproduce high reality image.

Figure 1 is classified major driving simulators developed at Korea, Japan and US as the performance of visual and motion systems. In this picture, the more channel of visual system, the field of view become widely. The other, the more axe of motion system, the motion become detail. Figure 2 is

the picture of Toyota driving simulator is developed the latest.



Performance of Motion System  
Figure 1. Classification of major driving simulators



Figure 2. Toyota Driving Simulator

Nevertheless, the driving simulator is not all mighty, because the performance of some subsystem is not enough to reproduce all human sense at all study. For example, the low performance without motion system can not reproduce the vibration sense for road pavement facility test (rumble strips, grooving, and etc).

This paper notifies a prepared knowledge of the driving simulator for study. The researcher using the driving simulator must understand the relation between the limit of its reproducibility and the human factors of road facilities. On the other hand, the developers of driving simulator give careful consideration to the reproduction of visual until test since drivers are see and estimate the road facility directly. Until driving simulator reproduces the drivers' sensation enough in corresponding with the test condition, it must develop continually.

## 2. THE HISTORY OF K-ROADS

### 2.1 design of K-ROADS

Since 2003, K-ROADS (KICT-Road Analysis Driving Simulator) is being developed at the HuRoSAS project (Human & Road Safety Analysis System) to establish highway criteria based on human factors such as road alignments and friction analysis model for road safety, establish road safety facility criteria on human factors for abnormal weather conditions, rumble strip design based on human factors and cause effect analysis and improvement on black spots. The K-ROADS was designed with the following two basic concepts.

- ☐ 360 degree Field of View

The visual system has 360 degree field of view to reproduce a dead angle on black spots such as at-grade intersection.

- ☐ Motion Generator of Suspension Type

The motion system has a motion generator of the suspension type to reproduce high frequency vibration made by irregular road surfaces.

## 2.2 System Configuration of K-ROADS

Since 2005, K-ROADS is been developed a full-scale driving simulator. Figure 3 shows the simulator in operation and the hardware configuration.



Figure 3. K-ROADS 2007

- ☐ Real-Time Vehicle dynamic Simulation System

The real-time vehicle dynamic simulation system is a key element of the driving simulator because the accurate prediction of vehicle motion with respect to driver input is essential. For chassis and suspension motion, both a 16 degree-of-freedom lumped mass model and 10 degree-of-freedom multi-body model with front Macpherson and rear trailing arm suspensions have been developed. Based on a simple linear relationship between the accelerator pedal angle and the throttle valve angle, the input to the engine model has been determined according to driving action. The engine speed and torque have been computed using a simple engine model. A power train model, consisting of a static torque converter and an automatic transmission with a transmission map, has been used to compute driving torque that will be included in tire rolling dynamics.

- ☐ Control Force Loading System

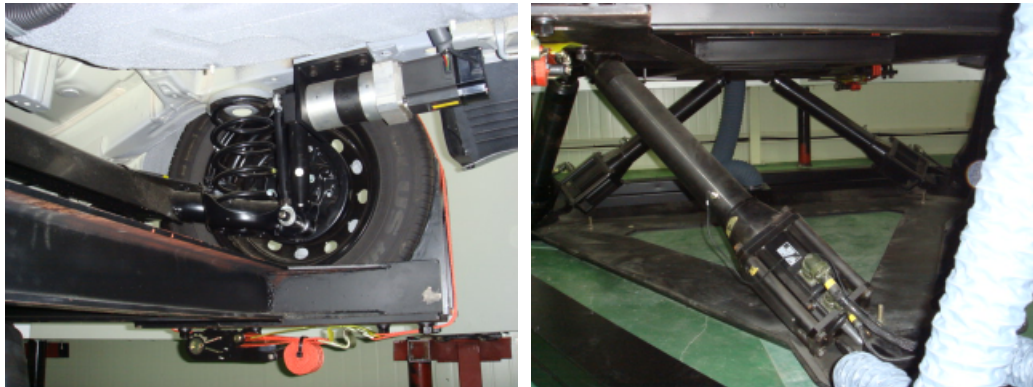
Since steering feel is the most sensitive proprioceptive cue in a control force loading system, generation of correct reaction torque of the steering wheel is important. In K-ROADS, aligning torque computed in the tire model has been used to determine the reaction torque needed for the steering wheel. The Hardware is ASWS (Active Steering Wheel System) which is made in TRW Conekt, England.

- ☐ Motion System

The kinematical structure of the motion system should be considered first in developing the motion system. A widely used 6 DOF Stewart platform reproduces rigid body motion smoothly, but has difficulty reproducing high frequency vibration on independent suspension and wheels. So, to solve this problem, the motion system has been designed with two types. One motion generator of suspension type reproduces high frequency vibrations made by irregular road surfaces, the other six- axes motion platform type reproduces low frequency vibrations made by road slop. This separated motion system reduces the simulation sickness. The kinematical structure of the motion system has an independent four-axle electromechanical motion generator at the suspension, and six-axle electromechanical motion generator under four-axle motion as shown in Figure 4.

This motion system reproduces high frequency vibrations including tire effect and instant acceleration of 3 DOF (pitch, roll, and heave), and low frequency vibrations include road slops of 2 DOF (pitch and roll) and instant long time acceleration when drivers are breaking.

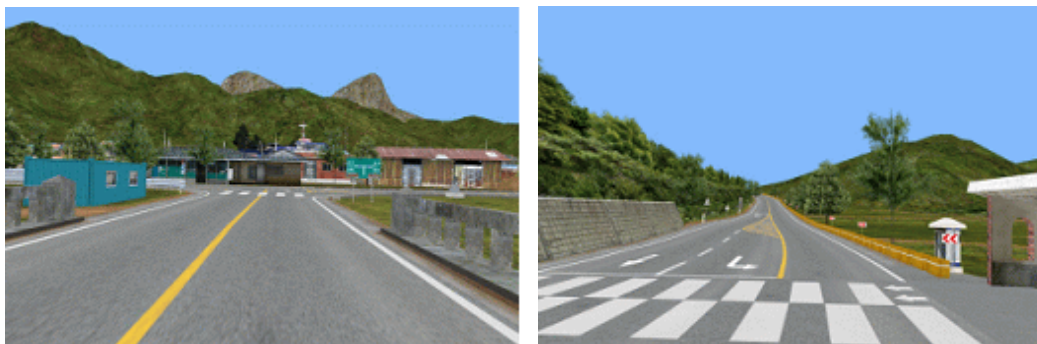
Drive logic of the motion system for generating realistic motion cues includes a washout algorithm, inverse kinematical analysis, and a control algorithm. The washout algorithm recovers the motion cue that is realizable within the motion envelope from the command cue of the vehicle simulation output. Chassis position and orientation information from the washout algorithm has then been converted into actuator lengths by the inverse kinematical analysis.



**Figure 4. Motion System (4 + 6 axes)**

#### □ Visual System

The visual system was designed with an 8 channel cylindrical screen of 360 degree field-of-view. A real time rendering engine is used —OSG (Open Scene Graph). It was developed in order to quickly render speed and real images for PC games. The front 3 channels have high-grade graphic cards for image generation and the other channels have medium-grade graphic cards, because drivers gaze at the front channels for driving. The first scenario was made a 4 km section of the national highway Route 30 using topographical maps, data of road alignments, and various objects' pictures on field, as shown in Figure 5.



**Figure 5. Images of Visual system**

Visual acuity of human is known decrease to half if the visual target is located  $2^\circ$  from the center. This is because the photoreceptor on the human's retina is composed of the cones which distinguish the color during the day and the rods which distinguish shadow using black and white. The 6-7 millions cones are centered on yellow spot in retina.

Visual acuity was defined by CIE (International Commission on Illumination) Korean illumination dictionary (1987). It was qualitatively defined as an ability to observe the minute portion of the gap, and defined quantitatively, as the degree of determination from distance. This was equivalent as the determined reciprocal degree of two adjoining objects.

In England and U.S.A. visual acuity is defined as a general driver, from reading on a Snellen chart at varying distances. The normal visual acuity is demonstrated as being able to read 1/3 inch (8.5mm) letter at 20ft (6m) distances on a bright condition which is indicated as a 20/20. Therefore, a 20/20 vision is considered as average visual acuity and 20/40 being lower and 20/10 being above average.

International Standard Organization (ISO, 1994) set the standard of the visual acuity test using Landolt ring rather than the letters. This ring has a hole which is 1/5 of its diameter. Normally if a person can determine 1.5mm hole in 7.5mm circle, 5m apart from him or her in one minute (1/60 degrees), he or she has a normal visual acuity which is 1.0 or 20/20.



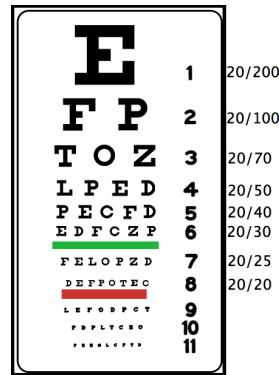


Figure 6. Snellen Chart



Figure 7. Korean visual acuity chart

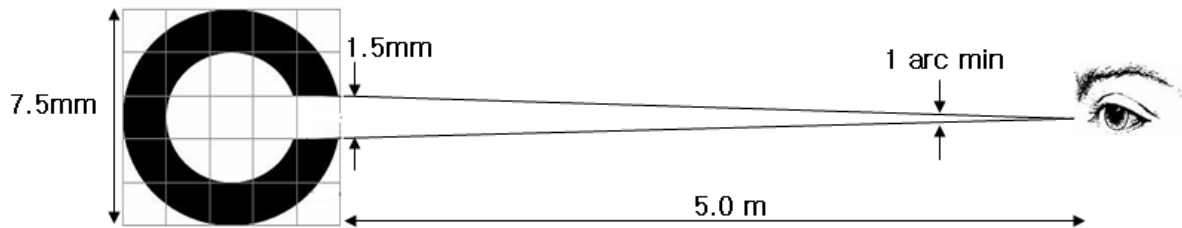


Figure 8. Visual angle (1 arc min) = normal visual acuity (1.0)

Resolution is an index that expresses the accuracy of the image, which is defined as the number pixels included in single image. The standard form is normally 1024 pixels wide and 768 pixels long (1024 x 768). Under same resolution, the smaller the screen, the more accurate vision was portrayed. However, since the projector extracts the actual size of the image, it results in a decrease of visibility. Therefore, pixel per inch (ppi) is used to measure the resolution of an image and dpi for a print's resolution.

However, in order to increase the sense of reality in driving simulator, a projector is usually used to lay out an image on the large screen. This decreases the resolution of the image, which makes the letter even more difficult to be recognized at a distance.

In the visual system, the center of the screen is the most distant part of the image. Therefore, this part of the image requires high-definition (HD). In our experiment, we were able to develop dual-resolution visual system that is used at the National Advanced Driving Simulator (NADS), known as the world largest ground vehicle driving simulator. The dual resolution visual system (DRVS) has 2 projectors. One A-projector plays part with the normal resolution image. The other B-projector is set up half distance from the screen, plays part with high resolution image, 1/4 size on screen.

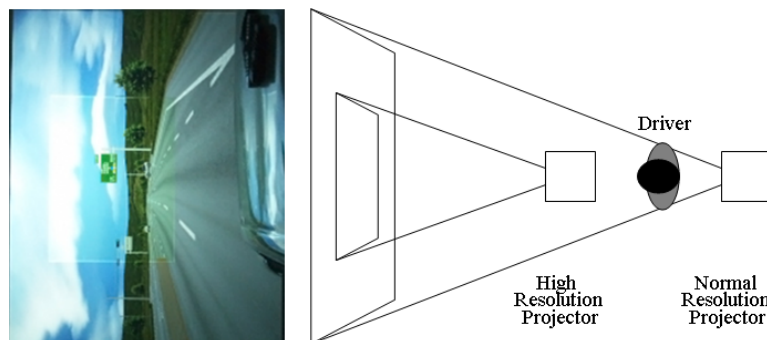


Figure 9. The dual resolution visual system

To experiment road sign legibility using virtual reality technique, limit of reproduced-vision (greatest visual acuity that the video system can read) in the visual system needs to be evaluated. In this experiment, with the principle of the measurement of vision, limit of reproduced-vision in the video system is measured with the method as follows.

To test whether the road signs can be read with DRVS, the limit of reproducible visual acuity (greatest visual acuity that he or she can read in the visual system) has to be evaluated and through out this study, such measurements was assessed using the following methods. Assuming the visual acuity of 1.0 in the visual system to be its minimum threshold, a person with higher visual acuity at a distance

of 5m can recognize an opened direction of the Landolt ring.

Using this relationship, the reproduced visual acuity is the reciprocal number of visual angle ( $\theta$ ) which is gained by using proportional expression of the distance, and the size of pixel. When distance, size of pixel, and visual angle is arranged using trigonometry, it is as follows.

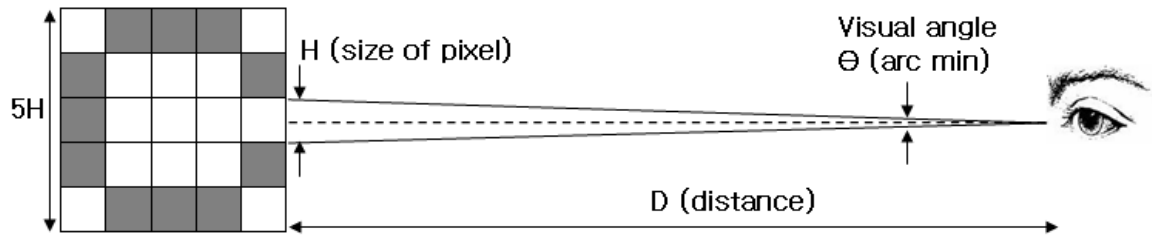


Figure 10. The relationship with size of pixel, distance, visual angle

Taking into account of this relationship between the visual acuity and the distance, the reproduced visual acuity can be re-expressed as a reciprocal number of visual angle( $\theta$ ), which is obtained using proportional expression of the distance, and the size of the pixel. When distance, pixel size, and the visual angle are arranged using trigonometry, an equation can be formulated.

In the equation, if the visual angle is very small, then length of the hypotenuse and the base line are practically the same. So, the value of the reproduced visual acuity can be calculated as follows.

- (1) Size of Pixel (H) = Size of the image/resolution
- (2) Distance (D) = distance between the driver and the screen
- (3) Visual angle ( $\theta$ ) =  $\sin^{-1} (H/D)$  [arc minute]
- (4) Reproduced visual acuity of visual system =  $1/\theta$

From this condition of this visual system, driver's minimum visual acuity or system's maximum visual acuity can be calculated as the chart below.

Table 1. Reproduced visual acuity by resolution

Conditions	Normal resolution	High resolution
Resolution (pixel)	1024 x 768	1024x768
Size of image	2.29m x 1.72m	1.12m x 0.795m
Resolution (ppi)	11.3 ppi	23.2 ppi
Size of pixel (H)	2.24mm	1.09mm
Distance (D)	2.9m	2.9m
Visual Angle	3.43 arc min	1.249 arc min
Visual Acuity	0.37	0.77

As a result, it is clear that the visual acuity from the virtual reality is similar to the reproduced visual acuity of visual system. This reproduced visual acuity in visual system is satisfied on 0.7 of the Korean Road Traffic Act. This shows that the legibility test of the road sign is possible. Also simple letter like 'A' and 'C' has a least legibility distance when the letter height is 5 pixels.

However road signs will have shorter legibility distance as the letter's complexity has high resolution.

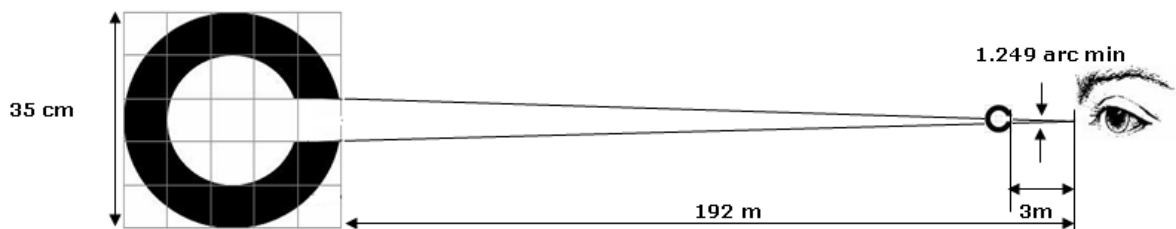


Figure 11. A least legibility distance of the road sign

#### □ Main Server

The main server takes charge of the management of road height, the sound control, the scenario control, the driving record and replay, and the communication of the vehicle simulation system and visual system. The main server reproduces the engine sounds according to engine rotation speed and the sounds according to road attributes such as normal pavement or grooving, because it has the information of road height and attributes. The main server sends the road's height data to the vehicle

simulation system, and receives the results of vehicle dynamics, and sends the position and direction on the road to the visual system within 5 msec. The scenario control exchanges the alternatives of speed humps. The subject's driving results such as time, speed, trace, force, position of vehicle are recorded 10 times per second in order to analyze and replay.

□ **Psychophysical Equipment**

K-ROADS has psychophysical equipment to analyze drivers' behaviors; EMR-8 (eye mark recorder), faceLab (eye& head tracing system), ECG (electrocardiogram), and EMG (electromyogram). These are utilized to search the relationship between drivers and the road.

### **3. THE APPLICATION OF THE DRIVING SIMULATOR**

#### **3.1 THE SCOPE OF THE STUDIES**

The driving simulator is a tool to the investigation of the drivers' behavior under various road environments. To investigate the drivers' behavior like real driving, one must inspect preliminary the reproducibility of human scenes (visual, motion, and etc) how much it has reality (speed, lighting, and etc). If it does not reproduce some scenes, one must inspect preliminary how much it have an effect to evaluation index (visibility, reduction of speed).

For Example, The legibility of road sign (Is the visual acuity at the driving simulator over 0.7?), the evaluation of delineator (Is the lighting's reality at driving simulator enough?), the evaluation of speed humps (Is the motional reality at driving simulator enough?), and etc.

#### **3.2 THE METHODS OF THE APPLICATION OF THE DRIVING SIMULATOR**

To apply the driving simulator to evaluation of the roads and road facilities, the researcher must carry out following orders;

- (1) Purpose of test
- (2) Literature review: study the human factor at the road facilities
- (3) Compare the limit of reproducibility of driving simulator with human factor
- (4) Make some virtual roads and scenarios
- (5) Virtual driving test
- (6) Analysis the human factor and driving results

#### **3.3 THE APPLICATION OF K-ROADS**

Since 2005, The K-ROADS has been applied to following major studies;

##### **(1) The effects of image speed hump with transverse grooving**

A road alignment which has a long straight section followed by sharp curve is dangerous, because drivers have the habit to accelerate on the long straight section and then accidents occur on the short curve as the result of speeding. This study evaluated the alternatives to speed humps in order to reduce speed safely and comfortably on roads with this incorrect road alignment. There are several speed control facilities to reduce speed on roads with wrong road alignment. The speed hump is dangerous at high speeds because drivers must reduce speed rapidly and because of the physical impact. The image hump provides less effect for drivers who already know of its presence. So, to resolve these matters, we propose a new type of speed control facility. An image hump with transverse grooving will be effective in reducing speed because the transverse grooving gives vibration and noise to drivers who are already aware of the presence of the image hump, but it does not give the hard physical impact to vehicles. This study found out that the image hump with transverse grooving is a safe speed control facility in order to reduce driving speed safely and comfortably on a straight section followed by a sharp curve, even if drivers are known the existence of image hump.

##### **(2) The drivers' behavior on long distance tunnel**

The drivers' recognition caused by his fatigue or road environment goes up and down. In the long distance tunnel, drivers can feel sleepy because the low visual stimulus. This study found out that drivers' recognition goes up if the special visual tunnel facilities are installed (example, the variable message signs are installed every 2km, the landscape paintings are installed every curves, and etc).

##### **(3) Human factors in processing information on road signs**

The essential function of road signs is to help lead road users to their destinations. The information on road signs should be recognized easily by the various types of drivers. This study's aim is to experiment with the driver's human factors that determine how the different age groups process information on road signs. The research was conducted using a driving simulator as follows: First, the age drops down the reading of information on a road sign. Secondly, the misreading rate was analyzed in order to understand how the subjects perceive and act on the information on the road signs. These results proved the effectiveness of this experimental model to determine the human factors that must be considered when creating safe and effective road facilities such as road signs.

#### **(4) The effects of FDWS (Fog Detect & Warning System) on vehicle flow characteristics**

Drivers obtain more than 90% of driving-related information through visual-perceptual activities. The visual abilities include vision, visual field, adaptation, and daze. Fog typically has a substantial impact on the view of drivers, regardless of their vision and every driver in the poor view is almost blind. That is why roadways have a high rear-end collision probability in a foggy day, and then it is very crucial to provide useful information (for example, linear road information, safety distances, and operation speeds) to drivers in fog.

This study is to develop FDWS (Fog Detect & Warning System) and to estimate the safety effects FDWS have on drivers' behaviors. FDWS was equipped with visibility meter (popular type), driver warning lamp, vehicle speed sensor, inter-vehicle distance sensor, and algorithm. FDWS is designed to enable a leading vehicle to give a warning message to a tailing vehicle, depending on the location and running speed of the leading vehicle. In the near future, it is expected that a virtual navigation system for a leading vehicle will be designed to prevent from collisions due to lack of information in fog. This study was performed to estimate the potential effects FDWS has on running speeds and headways in fog.

#### **4. CONCLUSION**

Quite a few of world driving simulator have been developed to evaluate the car parts, the road and traffic safety by investigating the driver's behaviors. But it is common that the simulator's limitation of its reproducibility is ignored and the its test results are applied to the industry, which is the main reason of producing the difference between the field test and virtual test. The driving Simulator, K-ROADS has been developed to evaluate various road alignments, safety facilities and scenic view by highlighting the visual scene's quality since 2003. It is applied to road facilities test after verifying the reproducibility of road facilities with human factor in advance. .

In conclusion, for the study using driving simulator, there should be an understanding and knowledge of limitations that simulator has which are mentioned as a prepared knowledge of the driving simulator for study.

The researcher using the driving simulator must understand that the simulator's limitation of the reproducibility of road facilities could affect the driver's human factors. On the other hand, the developers of driving simulator give a careful consideration to the reproduction of visual scenes since drivers are used to estimate the road facility from the visual scene directly. Until a driving simulator could reproduce the real driving sensation enough in accordance with the test purpose, it must be developed continually.

#### **AFFILIATIONS**

- ☐ **AmViEnt Inc.:** developed the visual system and system integration.
- ☐ **Inno Simulation Inc.:** developed the test vehicle and motion system.

#### **REFERENCES**

1. Development of Human and Road Safety Analysis System, Report 2007-091, Korea Institute of Construction Technology 2007.
2. David Shinar, Psychology on the road: the human factor in traffic safety, John Wiley and Sons Inc., New York, 1978.
3. Jong-min Kim, Kwan-sub Noh, A study on the effects of alternatives to speed humps using a driving simulator, Journal of Mechanical Systems for Transportation and Logistics, Vol.1, No.2, 2008.
4. Jong-min Kim, Suk-ki Lee, Development of driving simulator for evaluating the legibility of road signs, 2nd International Conference on Applied Human Factors and Ergonomics, 2008.